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Analysis of Heat Gain in Computer Laboratory and Excellent Centre by using CLTD/CLF/SCL Method

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Abstract

Performance of air conditioning system is closely related to heat gain that generated inside the particular room. The amount of heat that generated in the particular room is depend on several factors such as position of the room relative to solar orientation, wall material, electric appliances and number of human occupied in the room. In order to determine heat gain in a room, these parameters have considered and presented in this paper. The method of heat gain determination is using Cooling Load Temperature Differential (CLTD) and Cooling Load Factors (CLF) based on ASHRAE 1997 Fundamental Handbook and then verified by data provided by contractor of building. The case study of the present work is only focused on two rooms specifically Computer Laboratory Room and Excellent Centre Room in Faculty of Mechanical Engineering, University Malaysia Pahang. From this calculation, it has been obtained that the highest heat gain in Computer Laboratory Rom and in Excellent Centre Room is 20458.6 W and 33541.3 W respectively. The assessment of cooling capacity produced by air conditioning system showed that the air conditioning produced over cooling for 23.7 and 25.8 percent for Computer Laboratory and Excellent Centre rooms. Management should reduce the cooling capacity produced by the air conditioning in order to reduce energy consumption.

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Keywords Heat gain; ASHRAE; Air Conditioning

1. Introduction

Most of tropical climate countries like Malaysia, Thailand, Singapore and Indonesia are very concern about cooling in building for comfort. Besides the comfort, there is great concern about energy consumption in building especially for air conditioning system. In Malaysia especially, most of all commercial offices occupied by air conditioning systems consume averagely 70 percent of the total energy consumption in a year. Therefore, an accurate cooling load calculation method should be applied for essential decisions regarding the required capacity of the air conditioning system, volumetric flow rates of air and the duct dimensions, building energy consumption due to air conditioning system, etc. are made [1-2].

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Over the years, several methods have been developed to estimate the building cooling load due to several heat sources [3]. ASHRAE has established one of the most widely known and accepted standards for the determination of design heating and cooling loads. Earlier ASHRAE heating and cooling load methods include the total equivalent temperature differential/ time-averaging method (TETD/TA), the transfer function method (TFM) and the cooling load temperature differential (CLTD)/solar cooling load (SCL)/cooling load factor (CLF) method [4]. The transfer function method (TFM) is a two-step procedure. For instance, the cooling load due to heat gain through the walls and roof is calculated in two steps. In the first step, the fabric heat gain is calculated using the conduction transfer function coefficients and in the second step, room transfer function coefficients are used to convert the heat gain into cooling load. Thus the accuracy of cooling load calculations using TFM depends very much on the accuracy of transfer function coefficients. Due to its user-friendliness, TFM is a widely used computer-aided load calculation method in air conditioning industry. Unlike the TFM method, the cooling load temperature difference (CLTD)/solar cooling load (SCL)/cooling load factor (CLF) method is a one-step method. In this method, the cooling load temperature difference (CLTD) is used for calculating the cooling load due to fabric heat gain by multiplying it with the UA-value of the building element (where U is the overall heat transfer coefficient of the building wall or roof and A is its surface area). Hourly values of CLTD for representative walls and roofs are available in the form of tables. These CLTD values are normally generated using the TFM method for the particular walls and roofs. Thus the CLTD/SCL/CLF method is much simpler than the TFM method and is also very widely used for manual calculation and estimation of building cooling loads. However, the accuracy of this method once again depends on the transfer function coefficients, if TFM is used for generating the CLTD values. It is also possible to generate the CLTD values for representative walls and roof using the heat balance method, and by solving the fundamental transient heat conduction equation with appropriate initial and boundary conditions using a suitable numerical method. As mentioned before, though this method requires the use of computers for generating the CLTD values, it can be used very well for all kinds of walls and roofs including those not covered under TFM [5-7].

Heat gain calculation in this paper involving two (2) rooms that directly related to air handling unit (AHU) for central unit air conditioning system of each. The first room is called computer laboratory (CL) and the second one is Excellent Centre (EC). The EC consists of seminar room (EC 1), student activity room (EC 2) and post graduate room (EC 3). These rooms are located at ground floor admin building. Figure 1 shows layout of the ground floor that showing the CL and EC.

The purpose of this calculation is to identify components of heat gain in order to conduct energy efficiency study of the whole building. Possibility to reduce heat gain in particular component will be identified and suggestion will be made in order to reduce energy consumption of air conditioning system. Heat gain in each room plays important role of air conditioning energy consumption. Less heat gain obtained in a particular room means less energy is needed to maintain air conditioning temperature at appropriate comfort.

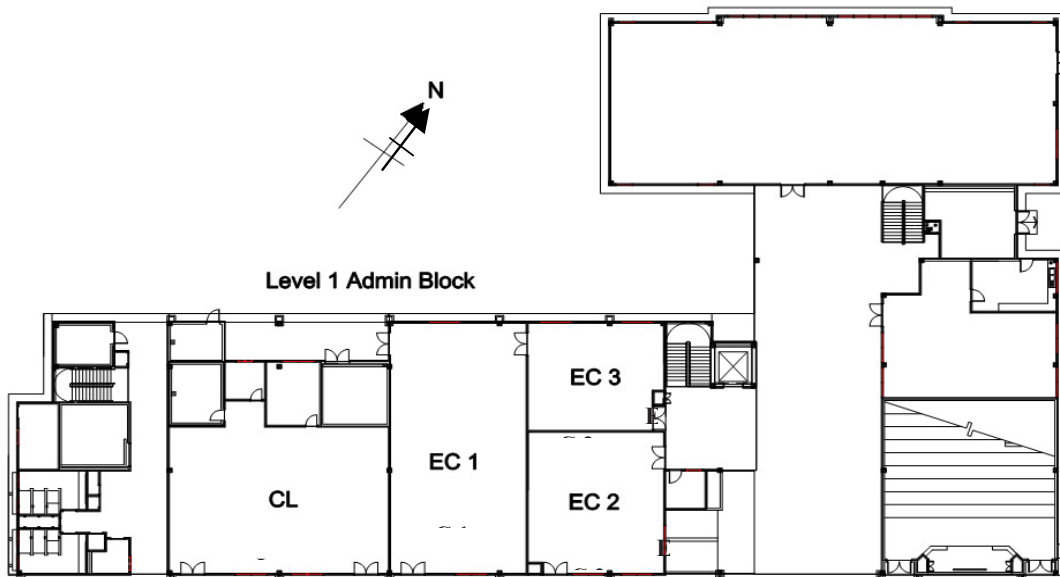


Fig. 1. Layout of the CL and EC

This calculation is based on ASHRAE 1997 and 2001 Fundamental Handbook for non-residential cooling and

heating load calculation. The calculation is carried out by using conventional calculation based on CLTD and CLF methods. The purpose of using conventional calculation is to identify each component of heat gain so that each of them can be analyzed in order to conduct energy efficiency study. There are several parameters have been measured in order to perform the calculation process. These parameters are room's specification, ambient temperature, room temperature, and relative humidity. The measurement had been conducted from 9 am to 5 pm for every hour. Within the period of time, the amount of heat gain for the particular room will be obtained and the highest heat gain will be considered as actual heat gain for the particular room. Generally, the sources of heat gain into a particular room can be divided into eight sources. Each of equation to determine the particular source of heat gain is shown by equation 1 until equation 11. Abbreviations used in this calculation are moderately complicated. However, each of the abbreviation is define clearly in this paper.

1.1. Conduction of Heat Gains Through Walls

Condition for the calculation is taken as below;

- Date: 21 July
- Location: Latitude 4°N
- Indoor temperature : 22.2°C
- Outdoor average temperature on the design day: 33°C

$$Q = UA \left(CLTD_c \right) \quad (1)$$

U is Heat Transfer Coefficient and can be determined using equation 2 and CLTD_c is Corrected Cooling Load Temperature Different and is expressed by equation 3.

$$U = \frac{1}{\sum R} \quad (2)$$

Where R is resistance.

$$CLTD_c = CLTD + (5.5 - Tr) (ta - 29.4) \quad (3)$$

and,

$$Ta = Tm - (DR/2) \quad (4)$$

Where;

T_m = outside design dry bulb temperature, °C

DR = daily temperature range, °C

Therefore, R is determined for every layer of the wall structure. The wall structure is considered as wall group 10 according to specification of designer and contractor as described in Table 18 (ASHRAE 1997, Chapter 28), wall conduction transfer function coefficient under Chapter 28. Wall resistance for each layer is taken from Table 11 (ASHRAE 1997, Chapter 28) and summarized in Table 1 in this paper.

Table 1 Wall resistance

Code No.	Element layer	R(m ² .°C/W)
A2	100mm face brick	0.076
B5	25mm insulation	0.587
C2	100mm low density concrete block	0.266
E0	Inside surface resistance	0.121
E1	20mm plaster	0.026
	Outside surface	0.059
	Inside surface	0.121
	Total	1.256

Therefore, by using equation 1 the overall heat transfer coefficient for wall is calculated to be 0.796 W/m².°C. This method shows sample of calculation for heat gain at 3 pm, therefore the CLTD also taken at 3 pm at two different directions as described below. The value is taken from Table 32 (ASHRAE 1997, Chapter 28) for wall number 10. The values of CLTD are as below;

- North West direction = 7

- South East direction = 18

Thus the value of CLTD_C will be two different values, that is

$$CLTD_C = 7 + \frac{5.5 - 22.2}{2} + \frac{6.5 - 29.4}{2} = 7.4^\circ\text{C for NW, and}$$

$$CLTD_C = 18 + \frac{5.5 - 22.2}{2} + \frac{6.5 - 29.4}{2} = 18.4^\circ\text{C for SE}$$

With the effective wall area of 48 m², the heat gain through the wall by conduction can be calculated using equation 1 as shown below.

$$\begin{aligned} Q &= UA(CLTD_C) \\ &= 0.796 (48) (7.4) = 22.8 \text{ W for NW} \\ &= 0.796 (48) (18.4) = 703.19 \text{ W for SE} \end{aligned}$$

1.2. Conduction Of Heat Gain through Glass Window

Window glass of the building and room had stated in manual master drawing as natural anodized aluminium frame window with single glass. Thus, overall heat transfer coefficient, U for glass is taken as 6.07 W/m².°C referring to Table 5 (ASHRAE 1997 Chapter 29). The following data are significant in order to determine rate of heat transfer through the glass. The total glass areas of all exposure are 7.2 m². By using Equation 1 and Equation 3, the conduction of heat gain through window is as below.

- CLTD at 3.00 pm. CLTD = 8°C
- CLTD_C = 8 + (25.5 – 23) + (27.75 – 29.4) = 8.4 °C
- Q = 6.07 × 7.2 × 8.4 = 367.11W

1.3. Conduction of Heat Gain through Door Structure

The type of door used is wood slab door with 6 percent glazing. The overall heat transfer, U for the door is 2.73 W/m².°C (ASHRAE 1997 Chapter 29, Table 7). During the peak time at 3 p.m, there are two directions of sunlight acting on the door which is on North West (NW) and South East (SE) direction. The exposure area for both conditions is 5m² and 10m². In order to determine the total heat gain through the door, Equation 1 is used. The sample is as below;

- CLTD were taken at 3.00 p.m at two direction
- North west direction (NW) = 10

- South east direction (SE) = 19 both CLTD is 8 °C

$$= 8 + (25.5 - 22.2) + (26.5 - 29.4) = 8.4 \text{ °C for both direction}$$

$$- Q = 2.73 \times 5 \times 8.4 = 114.66 \text{ W for NW}$$

$$- Q = 2.73 \times 10 \times 8.4 = 229.32 \text{ W for SE}$$

1.4. Solar Radiation Through Glass

Rate of heat transfer by radiation through window glass must be considered in order to calculate total heat gain in the room. The glass is consider as a without shading type with its shading coefficient (SC) is 0.85 taken from Table 11 (ASHRAE 1997, Chapter 29). The glass area are divided into two direction of sunlight; North West direction (NW) with 2.4 m² of area, A and South East direction (SE) with 4.8 m² of area, A. The magnitude of heat gain by solar radiation through glass is;

$$Q = SC \times A \times SCL \quad (5)$$

SCL is solar cooling load and the magnitude is taken from Table 36 (ASHRAE 1997, Chapter 28) for both directions as been mentioned above. Therefore;

$$SCL = 202 \text{ W/m}^2 \text{ for NW and } 161 \text{ W/m}^2 \text{ for SE}$$

Thus;

$$Q = 0.85 \times 2.4 \times 202 = 412.08 \text{ W for NW direction}$$

$$Q = 0.85 \times 4.8 \times 161 = 656.88 \text{ W for SE direction}$$

1.5. Heat Gain from Lighting

Both rooms are using same type of light which is Fluorescent 900 mm, T12 lamp with 30W of its load. The fluorescent lights have its own value of ballast factor, B.F which is 1.25. Ballast factor is special allowance factor. By using the Equation 6, the calculation had been done as shown below;

$$Q = W F_u F_{sa} CLF \quad (6)$$

Where;

W is total light wattage

F_u = Use factor, taken as 1.0

F_{sa} = Special allowance factor, taken as 1.25

Cooling load factor, CLF = 1 for cooling off at night or during weekend is applied based on equation 9 or 46 in Table 29 (ASHRAE 1997, Chapter 28).

Thus,

$$Q = 30 \times 60 \times 1.25 \times 1 \times 1 = 2325 \text{ W}$$

1.6. Heat Gain from People

Heat gain by people is divided into two types which is sensible heat and latent heat. During the shutdown of all electricity, the cooling load factor was increase due to heat produce by an interior structure and exterior structure. In this case, a CLF of 1.0 should be used. As this factor, CLF = 1.0 were taken as maximum value for designing the room. From Table 3 (ASHRAE 1997, Chapter 28), solar heat gain (SHG) produces by each people is 75W for sensible heat and 55W for latent heat. The number of the people in this room is about 42 peoples in peak condition. Therefore, the heat gain from people is determined from equation 7 and 8. The calculations are as below;

$$Q_s = q_s \times n \times CLF \quad (7)$$

$$Q_L = q_L \times n \quad (8)$$

Thus;

- $Q_{\text{sensible}} = n \times SHG \times CLF$
 $= 42 \times 75 \times 1 = 3150 \text{ W}$
- $Q_{\text{latent}} = n \times LHG$
 $= 42 \times 55 = 2310 \text{ W}$
- Therefore, the total heat gain produce by people in peak time is 5460W.

1.7. Heat Gain from Appliances

The room has 42 desktop computers and each computer are consumes about 155W of power. The power is consider as combination between monitor and central processing unit (CPU). The value is taken from Appendix A15. Cooling load factor (CLF) is equal to 1 was taken because the power is produce when an air conditioning is switch off heat was absorbed from the appliances is taken as maximum. Thus, Equation 9 is applied to compute heat gain from appliances as shown below;

$$Q = q \times n \times CLF \quad (9)$$

Where;

q = heat gain per equipment

n = number of equipment

CLF = cooling load factor for appliances

The calculation is referred to Table 8 (ASHRAE 2001, Chapter 29), whereby the combination of heat gains per equipment is taken as 155 watt with 42 units computers in the lab, therefore;

$$Q = 155 \times 42 \times 1 = 6510 \text{ W}$$

1.8. Heat Gain from Ventilation

Ventilation is the process of changing or replacing air in any space to control temperature or remove moisture, odors, smoke, heat, dust and airborne bacteria. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. To determine the heat gain from ventilation process, the psychrometrics chart is used to find the outdoor and inside humidity. Volume flow rate is taken at 0.008 m³/s per person from Table 2 (ASHRAE Standard 62-1999) in laboratories type space. Therefore the value of air ventilation rate is 0.42 m³/s. Equation 10 and 11 are applied to determine sensible and latent from ventilation.

- $Q_s = 1.23 \times \dot{Q} \times \Delta T$
 $= 1.23 \times 0.336 \times (33 - 28) = 2.07 \text{ kW}$
- $Q_L = 3010 \times \dot{Q} \times (W_o' - W_i')$
 $= 3010 \times 0.336 \times (0.0155 - 0.0102) = 6700.26 \text{ W}$
- Total heat gain from the ventilation flow is 711.61W.

Where;

Q_s, Q_L = sensible and latent cooling loads from ventilation air, kW

\dot{Q} = air ventilation rate m³/s

ΔT = temperature difference between outdoor and inside air, °C

$W_o' - W_i'$ = outdoor and inside humidity difference, gr water/kg. dry air

All of above equations and sources of data are summarized in Table 2.

Table 2 Summary of equation and sources for calculation

Type of Heat Gain	Equation Used	Sources
i) Conduction of Heat Gains Through Walls	$Q = UA CLTD_C$ $U = \frac{1}{\sum R}$ $CLTD_C = CLTD + (5.5 - Tr) + (a - 29.4)$	Table 11, Table 18 and Wall 10 Table 32, ASHRAE 1997, Chapter 28.
ii) Conduction Of Heat Gain through Glass Window	$Q = UA CLTD_C$ $U = 6.07 \text{ W/m}^2 \cdot ^\circ\text{C}$ $CLTD_C = CLTD + (5.5 - Tr) + (a - 29.4)$	Table 5 ASHRAE 1997, Chapter 29. Table 34 ASHRAE 1997, Chapter 28
iii) Conduction of Heat Gain through Door	$Q = UA CLTD_C$ $U = 2.73 \text{ W/m}^2 \cdot ^\circ\text{C}$ $CLTD_C = CLTD + (5.5 - Tr) + (a - 29.4)$	Table 7 ASHRAE 1997, Chapter 29.
iv) Solar Radiation Through Glass	$Q = SC \times A \times SCL$ Shading Coefficient = 0.85	Table 11 ASHRAE 1997, Chapter 29. Zone D, Table 36 ASHRAE 1997, Chapter 28.
v) Heat Gain from Lighting	$Q = W F_u F_{av} CLF$	Equation 9 or 46 ASHRAE 1997, Chapter 28.
vi) Heat gain from people	$Q_s = q_s \times n \times CLF$ $Q_L = q_L \times n \quad [\text{W}]$	Table 3 ASHRAE 1997, Chapter 28.
vii) Heat Gain from Appliances	$Q = q \times n \times CLF \quad [\text{W}]$	Table 8 ASHRAE 2001, Chapter 29.
viii) Heat Gain from Ventilation	$Q_s = 1210 \times \dot{Q} \times \Delta T \quad [\text{W}]$ $Q_L = 3010000 \times \dot{Q} \times (W_o' - W_i') \quad [\text{W}]$	Table 2 ASHRAE Standard 62-1999.

2. Result and Discussion

Ventilation is the process of changing or replacing air in any space to control temperature or remove moisture. Sample of calculation that has been described in previous section discusses a method in how to determine heat gain in a particular room. For analysis of heat gain that has been conducted from 9.00 am until 5.00 pm, it showed that the tabulation of heat gain is different and it has been summarized in Table 3. Meanwhile Figure 2 and Figure 3 show graph of the heat gain for the particular time. From six types of heat gain into the laboratory, they can be classified into two type of heat gain which is external and internal heat gain. Internal heat gain is due to the appliances, people and lighting. Meanwhile exterior heat gain is due to heat conduction, heat radiation and heat gain due to ventilation.

From the calculation, heat gains due to internal sources are fixed. This is due to constant heat produce by appliances such as computer and projector, and also constant heat that has been produced by lighting and people as well. Pattern of heat gain from 9 am until 5 pm shows consistent in its increment and reduction as can be observed that the heat gain is increased at 10 am and 11 am then decreased for the next two hours. The heat gain then increased again for 2 pm and 3 pm then decreased again at 4 pm and 5 pm. The increment of heat gain is much

influenced by external heat gain which is heat gain due to conduction, radiation and air ventilation.

Pattern of heat gain in these two rooms are the same where peak heat gain occur at 11 am at the morning and in afternoon, the peak heat gain occur at 3 pm. Since the heat gain is depend on external heat gain because of the internal components of heat gain are constant, there is not much work that can be done in order to decrease the heat gain in order to control power consumption of air conditioning system. A suggestion can be addressed here that possible to be implemented which is reduce shading coefficient of window glass. There are two methods that can be implemented here which is laminate the window glass with ultraviolet film and assemble outside owning

Cooling load analysis has been conducted on the both air handling unit (AHU) operated for CL and EC. Data for analysis such as temperature of chilled water, temperature of air, flowrate of chilled water and air are taken from building automated system (BAS). It has been found that the cooling capacity is obtained to be

Table 3 Summary of heat from 9.00AM until 5.00PM

Type of Heat Gain	Location	Heat Gain (W)								
		9AM	10AM	11AM	12PM	1PM	2PM	3PM	4PM	5PM
i) Conduction of heat gains through walls, glass window and door	CL	207.2	287.7	533.4	732.7	893.8	1084.8	1326.4	1402.8	1555.7
	EC	275	396.5	782	1075.1	1318	1568.7	1933.1	2033.4	2234
ii) Solar Radiation Through Glass	CL	1483.1	1532	1426	1215.8	989.4	969	1069	1162.8	1187.3
	EC	2966.2	3064.1	2851.9	2431.7	1978.8	1938	2137.9	2325.6	2374.6
iii) Heat Gain from Lighting	CL	2325	2325	2325	2325	2325	2325	2325	2325	2325
	EC	4800	4800	4800	4800	4800	4800	4800	4800	4800
iv) Heat gain from people	CL	5460	5460	5460	5460	5460	5460	5460	5460	5460
	EC	14300	14300	14300	14300	14300	14300	14300	14300	14300
v) Heat Gain from Appliances	CL	6510	6510	6510	6510	6510	6510	6510	6510	6510
	EC	2325	2325	2325	2325	2325	2325	2325	2325	2325
vi) Heat Gain from Ventilation	CL	3768.2	4067.3	4067.3	3561.6	3860.6	3768.2	3768.2	2849.3	2343.6
	EC	9869.2	10652.4	10652.4	9328	10111.2	9869.2	9869.2	7462.4	6138
Total heat gain	CL	19753.5	20182	20321.7	19805.1	20038.8	20117	20458.6	19709.9	19381.6
	EC	34535.4	35538	35711.3	34259.8	34833	34800.9	35365.2	33246.4	32171.5

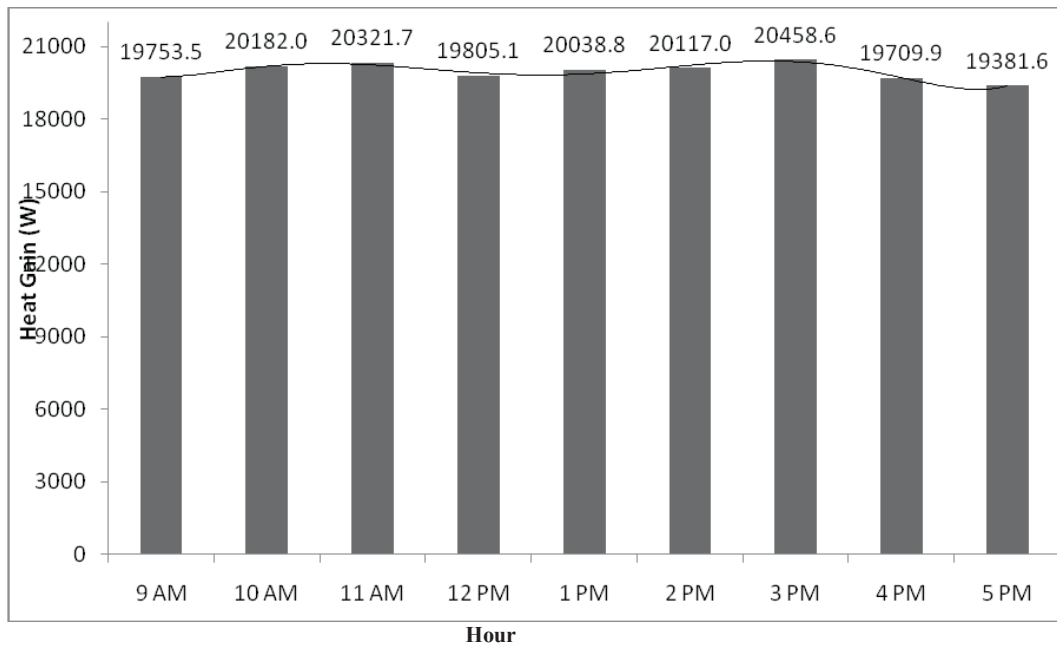


Fig. 2. Graph of heat gain in Computer Laboratory (CL)

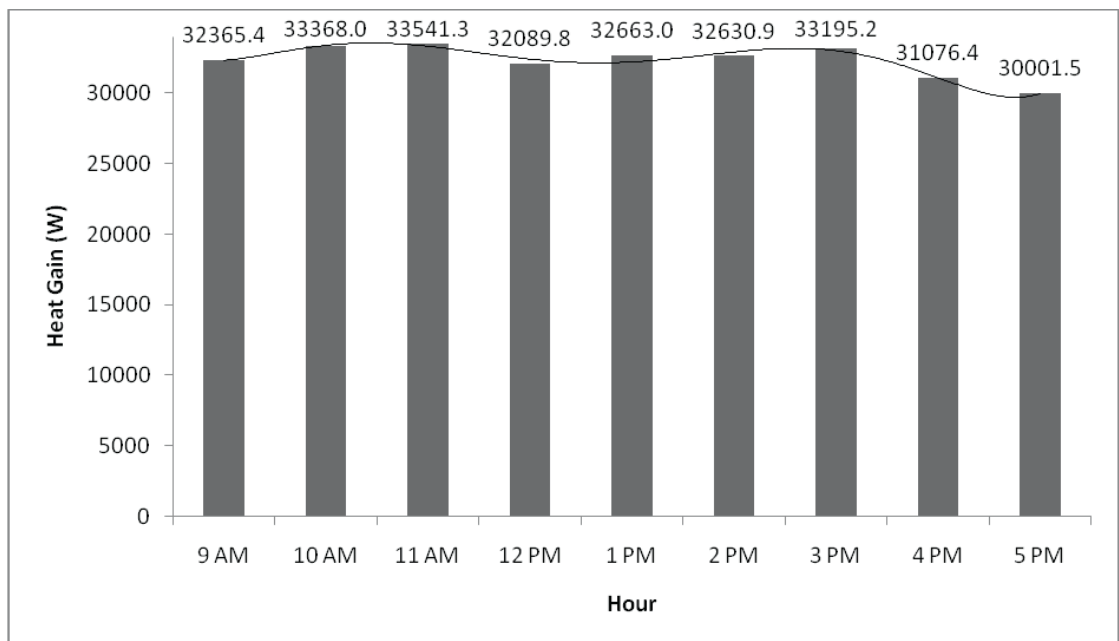


Fig. 3. Graph of heat gain in Excellent Centre (EC)

25.3 kW and 42.2 kW for CL and EC respectively. Therefore, the system is found that to be over cooling and consequently consumes over electricity energy

3. Conclusion

There are two main sources of heat gain in this work which is external and internal heat gain. Internal heat gain is a parameter that difficult to be reduced unless replacing current lighting with energy saver bulb. It has been mentioned above that the easy way to reduce component of external heat gain is by reducing shading coefficient of solar radiation. The peak solar radiation is occurred at 10 am which contributes 7.6 and 8.6 percent in CL and EC respectively. The reduction of heat gain from component of solar radiation gives slightly effect to the total heat gain and also slightly reduces energy consumption of air conditioning system. The peak heat gain is occurred at 3 pm with the amount of 20458.6 watt for CL and at 11 am with the amount 33541.3 watt for EC. With the mentioned cooling capacity analysis, it has been found that the air conditioning system produces 23.7 percent over cooling for CL and 25.8 percent for EC. Immediate action need to be taken to reduce the cooling capacity consequently reduces energy consumption of air conditioning system.

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